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MULTI-POINT DESIGN OPTIMIZATION OF FUEL INJECTION USING FLEXIBLE GEOMETRY FOR SCRAMJET-POWERED ASCENT FLIGHT VIA SURROGATE-ASSISTED EVOLUTIONARY ALGORITHMS

Abstract

Scramjet engines offer great potential for reusable, and economical systems for access-to-space. The last decade has seen significant developments in the domain of scramjet propulsion including flight experiments conducted in the HyShot II in 2002 and X-43A flight programs in 2004, followed by HIFiRE 7 in 2015. One of the key challenges in scramjet design is to maintain adequate mixing and low total pressure loss for sustained operation. Parametric investigations have been performed in preceding studies employing inclined porthole fuel injectors and various injector geometries. However, there still remains room to examine the optimal design configurations and underlying physics by exploring a broader design space.

The present work aims to investigate optimal injector shapes using flexible geometric representation and injection conditions that maximize mixing efficiency and minimize total pressure loss. Multi-objective optimization is performed to achieve these objectives at two design conditions simultaneously, i.e., crossflow Mach numbers of 2.5 and 3 at the combustor entrance, which correspond to flight Mach numbers of 5.3 and 6.3, respectively, on an ascent trajectory at a constant dynamic pressure.

Fuel (hydrogen) is injected into the crossflow (air) in the combustor. The injector shape is represented by a 4th-order Bezier curve at a constant fuel/air equivalence ratio with sonic injection. Four geometric parameters are employed as the decision variables, along with injection pressure and angle. Steady, viscous, turbulent flowfields are simulated by means of computational fluid dynamics (CFD) that solves the Reynolds averaged Navier-Stokes equations. Surrogate models are built based on the solution archive of CFD evaluations. Multi-point, multi-objective design optimization studies are conducted via the surrogate assisted evolutionary algorithm (SAEA), where individuals (injector designs) represented by the decision variables are evolved in the population pool via genetic operations including crossover and mutation over generations.

Flowfields are scrutinized for optimum injector designs selected from the Pareto optimal front. Experimental measurement is conducted in the high-speed mixing/combustion testing facility for the representative optimum designs in comparison with the baseline case. SAEA-based optimization is also performed on GPU (graphics processing unit) with a substantially large population to accurately capture the behavior of the performance parameters in response to the design parameters. Variance-based sensitivity

analysis is performed to identify influential design parameters on the injector performance. In so doing, insights are gained into the key design factors and underlying flow physics for efficient and robust injector design for high-performance scramjet propulsion.